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THESIS

ANALYZING THE COST EFFECTIVENESS
OF USING FLIGHT SIMULATORS IN THE
ISRAELI AIR FORCE

by

Uzzi Rozen

December 1985

Thesis Advisor: Roger Evered

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Analyzing the Cost Effectiveness of Using Flight Simulators in the Israeli Air Force

by

Uzzi Rozen
Lieutenant Colonel, Israeli Air Force

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1985

ABSTRACT

During the last decade flight simulators have been increasingly used in the training of the Israeli pilots. The increasing cost of a training flying hour, the shrinking training airspace over Israel since 1979, and the high performance standards required of the Israeli Air Force air crews were the accelerator factors in this process.

This thesis describes a way to analyze the cost effectiveness of the present mix of flight simulators and flying hours in the training process of the I.A.F. air crews. The jet fighters, helicopters, and transportation communities are used as examples to demonstrate the implementation of the analysis. These examples give the reader a general picture of the cost effectiveness of using flight simulators in the I.A.F.

TABLE OF CONTENTS

I. INTRODUCTION - 8

A. PURPOSE - 8

B. STUDY METHODOLOGY - - - - - - - - - - - - - - - - - 9

C. THESIS ORGANIZATION - - - - - - - - - - - - - - - - 10

II. FLIGHT SIMULATOR - AN OVERVIEW - - - - - - - - - - - - - 11

A. HISTORICAL DEVELOPMENT - - - - - - - - - - - - - - 11

B. SIMULATORS' DEGREE OF FIDELITY - - - - - - - - - - 14

C. ADVANTAGES AND LIMITATIONS OF USING FLIGHT SIMULATORS - - - 18

III. TRAINING COST EFFECTIVENESS METHODOLOGY - - - - - - - 20

A. GENERAL - 20

B. TRAINING COST EFFECTIVENESS CRITERION - - - - - - 21

C. TRAINING EFFECTIVENESS SUBMODEL - - - - - - - - - - 22

D. TRAINING COST SUBMODEL - - - - - - - - - - - - - - 27

E. TOTAL TRAINING COST - - - - - - - - - - - - - - - - 31

F. IS THE EXISTING TRAINING MIX COST EFFECTIVE?- - - 33

G. THE COST EFFECTIVE TRAINING MIX - - - - - - - - - - 34

IV. TRAINING COST EFFECTIVENESS ANALYSIS - AN ILLUSTRATION 36

A. GENERAL - 36

B. TRAINING COST EFFECTIVENESS - THE JET PILOT - - - 37

C. TRAINING COST EFFECTIVENESS - THE HELICOPTER PILOT - - - - - - - - - - 43

D. TRAINING COST EFFECTIVENESS - THE TRANSPORTER PILOT - - - - - - - - - - 47

E. SUMMARY - 53

V. CONCLUSIONS AND RECOMMENDATIONS - - - - - - - - - - - 55

LIST OF REFERENCES - 59

INITIAL DISTRIBUTION LIST - - - - - - - - - - - - - - - - - 60

LIST OF TABLES

III - 1	TRAINING MIX - A PILOT VIEW - - - - - - - - - - - -	25
III - 2	TRAINING MIX - STATISTICAL SUMMARY - - - - - - - -	26
IV - 1	TRANSFER EFFECTIVENESS RATIO - JETS - - - - - - -	37
IV - 2	COST EFFECTIVENESS - PRESENT JET TRAINING MIX - -	41
IV - 3	THE COST EFFECTIVE TRAINING MIX - JETS - - - - -	42
IV - 4	TRANSFER EFFECTIVENESS RATIO - HELICOPTERS - - -	43
IV - 5	COST EFFECTIVENESS - PRESENT HELICOPTER - - - - - TRAINING	47
IV - 6	TRANSFER EFFECTIVENESS RATIO - TRANSPORTERS - - -	48
IV - 7	COST EFFECTIVENESS - PRESENT TRANSPORTERS MIX - -	52
IV - 8	THE COST EFFECTIVE TRAINING MIX - TRANSPORTER - - PILOT	53
V - 1	DEMONSTRATED TRAINING COST EFFECTIVENESS - - - - ANALYSIS - RESULTS	57

LIST OF FIGURES

I - 1	The Study Methodology - - - - - - - - - - - - - - -	9
III - 1	The Training Cost Effectiveness Model - a Flow Chart - - - -	21
III - 2	The Isoquant Curve - - - - - - - - - - - - - - - - -	23
III - 3	Constructing The Effectiveness Isoquant - a Flow Chart - - -	24
III - 4	The Effectiveness Isoquants - - - - - - - - - - - -	27
III - 5	Cost Submodel - a Flow Chart - - - - - - - - - - -	28
III - 6	Training Cost Curves - - - - - - - - - - - - - - -	32
III - 7	Relating The Effectiveness Isoquant and The Cost Curve - - - - -	33
III - 8	Solving The Cost Effective Training Mix - a Flow Chart - - -	34
IV - 1	The Effectiveness Isoquants - Jets - - - - - - - -	36
IV - 2	The Training Cost Curves - Jets - - - - - - - - - -	40
IV - 3	The Effectiveness Isoquants - Helicopters - - - -	44
IV - 4	The Training Cost Curves - Helicopters - - - - - -	46
IV - 5	The Effective Isoquants - Transporters - - - - - -	49
IV - 6	The Training Cost Curves - Transporters - - - - -	51

I. INTRODUCTION

A. PURPOSE

The important role of air superiority in the defense of Israel has always been in conflict with the requirements of a wealthy and healthy economy as a foundation to a democratic independent state. About a decade ago, the increasing cost of training flying hours, and the increasing rate of required flying training hours to attain air superiority reached the point at which economic resources were insufficient. The "blanket" is too short; no matter how we use it, a part of our body will be exposed to the cold. This situation, and the shrinking airspace as a result of the peace treaty with Egypt in 1979, were the main causes for accelerating the use of flight simulators in the Israeli Air Force. During the last decade a few advanced simulators were acquired and were used for some of the training tasks. For other training tasks the pilots use commercial and military simulators outside the country. The attitude toward the simulator has changed since the days in which simulators were used for procedures and instrument flying training only, and the feeling among most of the fliers and command levels is that the simulator is paying back what had been invested in it.

No comprehensive cost-effective analysis for selecting the proper mix of the flying and simulator training hours in the I.A.F. has been done. The purpose of this study is to provide

an analytic tool to perform such an analysis. Two questions initiated the study:

(a) Is the existing mix of flying and simulator training hours cost effective?

(b) What is the potential cost effectiveness mix of flying and simulator training hours?

B. STUDY METHODOLOGY

The methodology that was chosen for this study is the one that is common to most of the cost effectiveness analysis. Figure I - 1 describes the study methodology.

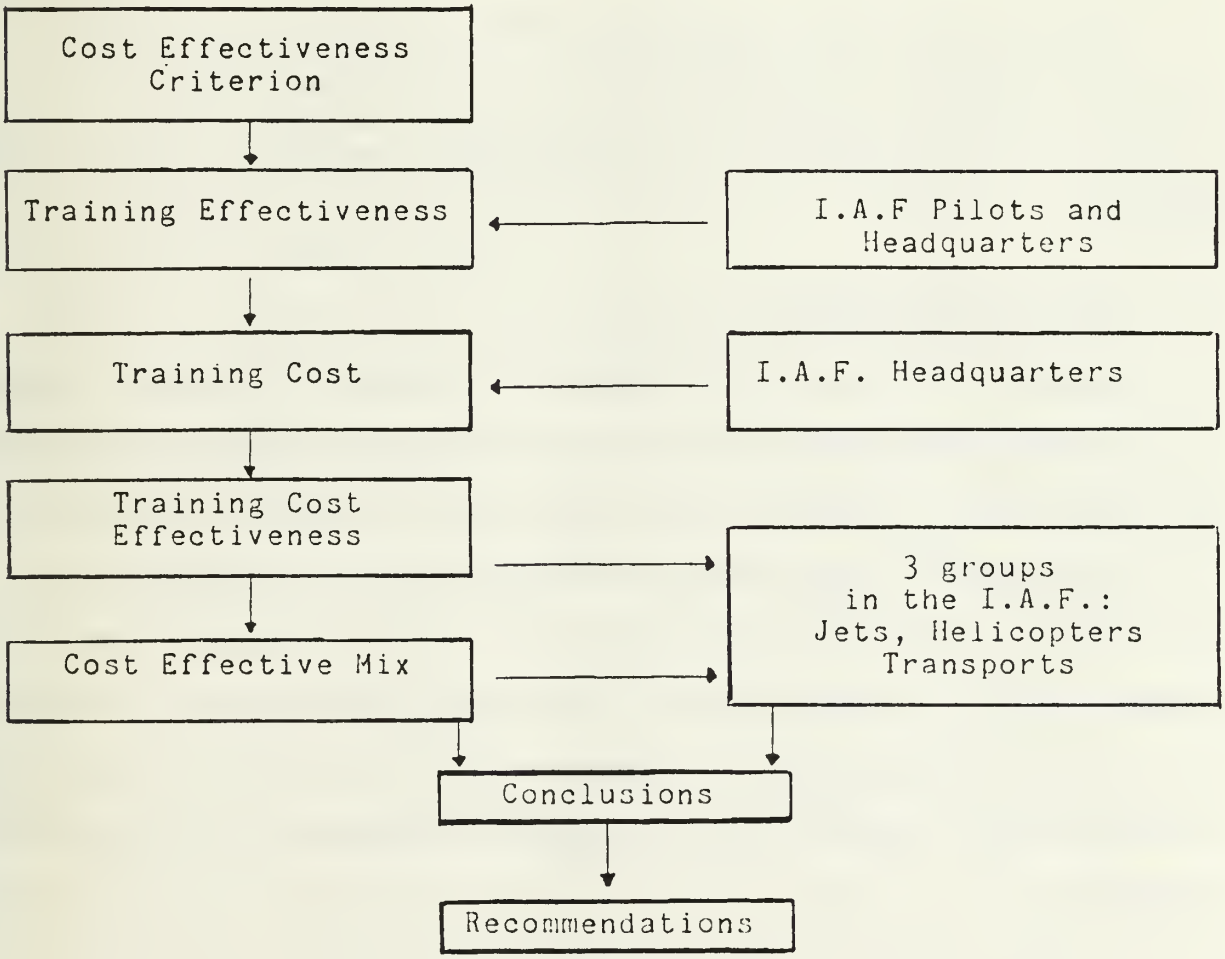


Fig. I - 1
The Study Methodology

(a) The first step in the study was to define the criteria that has to be used in the analysis.

(b) Data about the potential effectiveness of using simulators was gathered from the I.A.F. Headquarters and a large group of I.A.F. pilots (58). This data was the foundation of developing a way of measuring flying training effectiveness.

(c) Data about the existing way of computing training cost and actual values was provided by the I.A.F.

(d) With the above-described data, a model to examine the two questions that are the foundation of this study was developed.

(e) Three communities in the I.A.F., jets, helicopters, and transports, have been chosen for the purpose of demonstrating the cost-effectiveness model.

Finally, the author presents some conclusions on the way that the two basic questions have to be examined, and on the results of the training cost-effectiveness analysis in the three groups.

C. THESIS ORGANIZATION

Chapter II provides a background on flight simulators including historical development, technology development, degree of fidelity, and the pros and cons of using simulators during the process of selecting the proper mix of training hours. Chapter III develops a methodology to analyze the cost effectiveness of using simulators, while Chapter IV demonstrates the use of the analysis in the three I.A.F. groups (Jets, Helicopters, and Transports). Finally, conclusions are summarized in the fifth chapter.

II. FLIGHT SIMULATORS - AN OVERVIEW

A. HISTORICAL DEVELOPMENT

The historical development of flight simulators seems to have followed, step-by-step, the development of the airplane itself. The requirement for such a development was stimulated by the hazards of flying, the skills required to pilot the airplane, the need for a training aid to supplement pilot instruction and, in the last decades, by the high cost of flying the jet airplanes.

Prior to World War I, a training device which came to be known as the "Penguin" was developed. It was a stubbed-winged aircraft capable of moving across large open spaces, but incapable of leaving the ground. [Ref. 1]

During the first war a training device which was produced in France used an aircraft fuselage based on a pivotal mount and incorporated compressed air which produced variations of response and aerodynamic feel with variations in speed. [Ref. 2]

In 1924, two English research workers, Reid and Burton, evaluated the importance of full cockpit simulation by measuring responses of pilots in a modified aircraft fuselage with functioning displays and controls. It was concluded that devices which required pilots to make responses on the ground to those made while airborne could be used to: (1) test the pilot's ability to fly and land successfully, (2) assess the rate of acquisition of flying skills, (3) train pilots on those particular motor

skills necessary for aircraft controllability, and (4) classify subjects for different forms of flying services. [Ref. 2]

In 1929, Roeber, a German inventor, proposed an apparatus for instruction in the navigation of vehicles in free space, utilizing a hydraulic system which would reproduce the physical movement of an airship like the motion systems of some present-day simulators.

Edwin Link completed the development of the first Link-Train, in 1929, which later became the famous ground trainer during the Second World War. [Ref. 1]

After the war, the development of computer technology, the increasing cost of flying training due to the high gas consumption of the jet engines and the complexity of the new airplanes accelerated the design and use of the flight simulators. During the last two decades, a major step has been taken in using the simulators. It has been changed from an instrument trainer to a visual trainer. The trainee pilot is no longer limited to a low degree of fidelity that is achieved by the instruments' reactions and by 3-6 degrees of motion freedom. Nowadays, a higher degree of fidelity is achieved by various techniques of visual simulation.

In the I.A.F., the first big step toward using these simulators was done after the 1967 War, during the years in which a new generation of airplanes appeared in the airspace over the country. The F-4 jet fighter, the CH-53 helicopter, and the C-130 transport were much more avionics-oriented than their ancestors. Those new airplanes were also much more expensive, considering the

flying hour cost. Step-by-step with the increasing power and capacity of the digital computers in those days, the 3-6 degrees of motion freedom simulators became an attractive supplement to the basic flying training tasks: procedures, emergencies, instruments and avionics.

The next step in using simulators was done in the late 1970's and the early 1980's as a result of losing about 75% of the training airspace over the Sinai Desert, which was an ideal military training space. The shrinking training space made the airspace over Israel one of the most crowded airspaces in the world. Many tactical training tasks such as low altitude high speed navigation have no space in which to be performed. The new restrictions on training pushed the I.A.F. to a new era of developing the use of simulators as a tactical training device, a concept that had high probability to be accomplished by the introduction of high fidelity visual simulators in the market.

Since the appearance of the visual simulators, the attitude of the fliers toward the simulator has been changed, no longer hating the simulator, but having a great respect for it as the major tool to improve tactical performance of the pilot.

The motivation for the next step of using simulators in the training mix is rooted in the great effect that the cost of flying hours has on the country's economy. For many years (and this is not going to be changed) air superiority has been one of the major components in the country's defense concept. The air superiority can be achieved by the technical performance

of the flying weapon systems and, mainly, by the air crews who are responsible for implementing the technical performance.

The function that describes the fliers quality is dominated by one important variable - total training hours. Those training hours are also a dominant variable in the defense budget function. Introducing the simulator in the training mix has the potential of balancing the way that the training hours affect the budget function, without changing the power of the training in the quality function.

B. SIMULATORS' DEGREE OF FIDELITY

The main performance criterion in the process of designing the simulator as a flight training device is the simulators' degree of fidelity. Degree of fidelity is the term that is used to describe what part of the pilot's real world is represented by the simulator, e.g., the famous old Link Simulator had a very low degree of fidelity, because it represented to the pilot only the instruments in the cockpit, with nothing of the world outside the cockpit or any of the physical forces that influence the pilot during a real flight. Having such a low degree of fidelity, the simulator then could be used mainly for procedures training.

Later on, when motion was introduced with the simulators, a few of the physical and physiological forces that affect the pilot in a real flight were simulated, and the use of such a simulator could be expanded to training tasks such as instrument flight.

Ten years ago, technology began to move toward the use of computers to create images. Unlike model boards, Computer Generated Images (CGI) simulators can be reprogrammed to create a variety of terrains and can also picture other aircrafts for combat training. The first step involved in the computer generated image system is to create the data base. Basic terrain contours are generally derived from digitized topological maps, and realistic details such as airports, roads and vegetation are added either by hand or by automatically duplicating standard models. The entire data base is stored in the computer as a large series of polygons. During the second step, the computer calculates the position and orientation of the simulated aircraft, decides what can be observed from this point and altitude, and then uses the data base to create thousands of colored and shaded polygons. Then comes the last step in which the images are sent to the display devices which project the images on a dome-like screen surrounding the forward portion of the simulator cockpit. [Ref. 2]

To increase details and improve an image in the computer generated images method, the number of edges that are used to define a scene is increased. As a result, the capacity and processing speed requirements from the hardware increase and the image generator becomes the main bottleneck in the simulation process. [Ref. 2]

The main way that simulator manufacturers are improving the realism of the data base without narrowing the above-described bottleneck is through "texturing." texturing is "painting"

patterns onto the polygons to disguise their blockiness. For example, in low level flight, trees look like abstract sculptures using the conventional computer generated images method; however, painting a pattern over each small square or "cell," one looks like a real tree. The patterns themselves are generated in advance either from photographs of real objects or by fractals. Fractals are patterns created by breaking up a surface into smaller and smaller irregular shapes that look the same at every scale. Since the parts of the polygon not covered by the pattern are transparent, the tree appears to have a ragged edge, rather than the blocky one of the polygon. In addition, as the viewer moves by the tree or other object, the image generator blends the pattern of one face with that of another coming into view so that a smooth, three-dimensional effect is created. [Ref. 3]

The visual simulators which use the Computer Generated Images and the Texturing methods put the degree of fidelity to a level that provides exact perspectiveness, near real time display of static and moving objects, quick visual environment changes or modifications, unlimited rate of maneuverability, and a relatively large area of flight coverage.

The existing degree of visual simulators' fidelity enable the users to introduce the simulator as a training device for a wide range of tactical training tasks such as air-to-air and air-to-ground combat maneuvers against active environment, air refueling and Nap on Earth navigation for helicopters.

The next generation of simulators moves from computer graphics to photographs that are taken by an aircraft that flies over

the area that has to be simulated. The photographs are scanned onto a videodisc, and then, during the training simulator flight, the computer predicts what photographs must be called up to represent the scene. Each photo is then distorted in orientation, scale and tilt to correspond with the position and direction of the simulated aircraft at a given instant. [Ref. 3]

The real-world photographs, combining with expanding and improving the display system, will push the degree of fidelity to a near real-world level, in which pilots can use the simulator as an operational training device. For example, a few hours before an operational mission, the pilot will use the simulator to train himself on the final leg of an air-to-ground mission, using a data base that consists of photographs that have been taken recently by a reconnaissance aircraft or by a satellite.

Following the image generation and display improvements, the mechanical clumsiness of the simulators is reduced by turning away from the standard approach of simulating accelerations by actual motions of the simulator cockpit. The manufacturers are using inflated seats and g-suits to simulate accelerations. For a hard right bank, for example, the seat would push forward against the pilot's back and the left side of the seat would inflate. [Ref. 3]

Finally, it has to be mentioned that for many basic flying training tasks, the non-visual simulator still produces a high degree of fidelity and is relatively cheap to use.

C. ADVANTAGES AND LIMITATIONS OF USING FLIGHT SIMULATORS

The advantages and limitations of using the simulator as a flying training device need to be considered before going into the process of selecting the proper mix of training. The advantages provided by using simulators include:

(a) A pilot can gain from experience without paying the consequences for a wrong decision or bad performance.

(b) A pilot has the opportunity to train in situations that are not available in the real training environment, but are expected to be part of the real operational environment.

Examples:

(1) Air-to-ground task against active surface-to-air missiles site.

(2) Landing in a low ceiling/low visibility condition.

(c) The pilot has the opportunity to be trained in emergency procedures that are not safe enough to be part of the real flying training.

(d) Time can be compressed -- making the time the pilot spends in the simulator more efficient, e.g., a final instrument approach for landing can be repeated without the real-world need to fly after every landing all the way back to the initial point.

(e) Feedback is immediate and usually much more accurate than in the real flying training. Results are not judged by the trained pilots or by the instructors, but measured and represented by the simulator on the basis of well-defined measurements of effectiveness (MOE).

(f) Cost saving is built in. A simulator training hour costs about 5%-25% of the relating training flying hour.

The limitations of using simulators include:

(a) A simplistic view of the real world may result from the simulator performance and the way of using it. In such a case, negative learning can occur in which the pilot will find himself using the wrong tactics or flying his plane in the wrong way for a specific real-world situation.

(b) Confusion may be created by the easiness of introducing overly complex situations.

(c) Although they are less expensive than flying hours, the absolute cost of using simulators is gradually increasing and, in contrast to airplanes, simulators are used only for training.

Balancing the pros and cons of using simulators has to be done by examining the effectiveness of the simulator in accomplishing the training tasks, the cost of using the simulator to accomplish the training, and then by a cost-effective analysis which considers the simulator as a component in the training mix. The result is the proper mix of flying and simulator hours.

III. TRAINING COST EFFECTIVENESS METHODOLOGY

A. GENERAL

The following analysis describes a suggested way of answering the two basic questions presented in the introduction:

(a) Is the existing mix of training, flying and simulator hours cost effective?

(b) What is the cost-effective potential mix of flying and simulator hours?

Two factors are usually involved in the process of cost-effectiveness analysis: (1) cost and (2) effectiveness. Relating cost to effectiveness is the easiest part of such an analysis and can be done either by fixing the cost and maximizing the effectiveness or by fixing the effectiveness and minimizing the cost. Much less obvious is the way of determining the cost and effectiveness of the system in examination or, in other words, how we measure the cost and the effectiveness of the system - in this case, how we measure the cost and the effectiveness of a certain mix of flying and simulator training hours.

In order to provide a way of measuring the cost and effectiveness, and relating them into a cost-effectiveness analysis that leads to answering the above questions, a model is developed and described in this chapter. Two assumptions are at the foundation of this model:

(a) The existing level of effectiveness in the training of the I.A.F. air crews is also the required level of effectiveness.

(b) Any large scale of training mix effectiveness experiments are impossible to execute. Using existing results of such experiments in the U.S.A.F., U.S. Navy and U.S. Army is limited due to variations in the effectiveness requirements between the I.A.F. and the various U.S. flying forces.

The flow chart in Fig. III - 1 describes the steps involved in developing and utilizing the model.

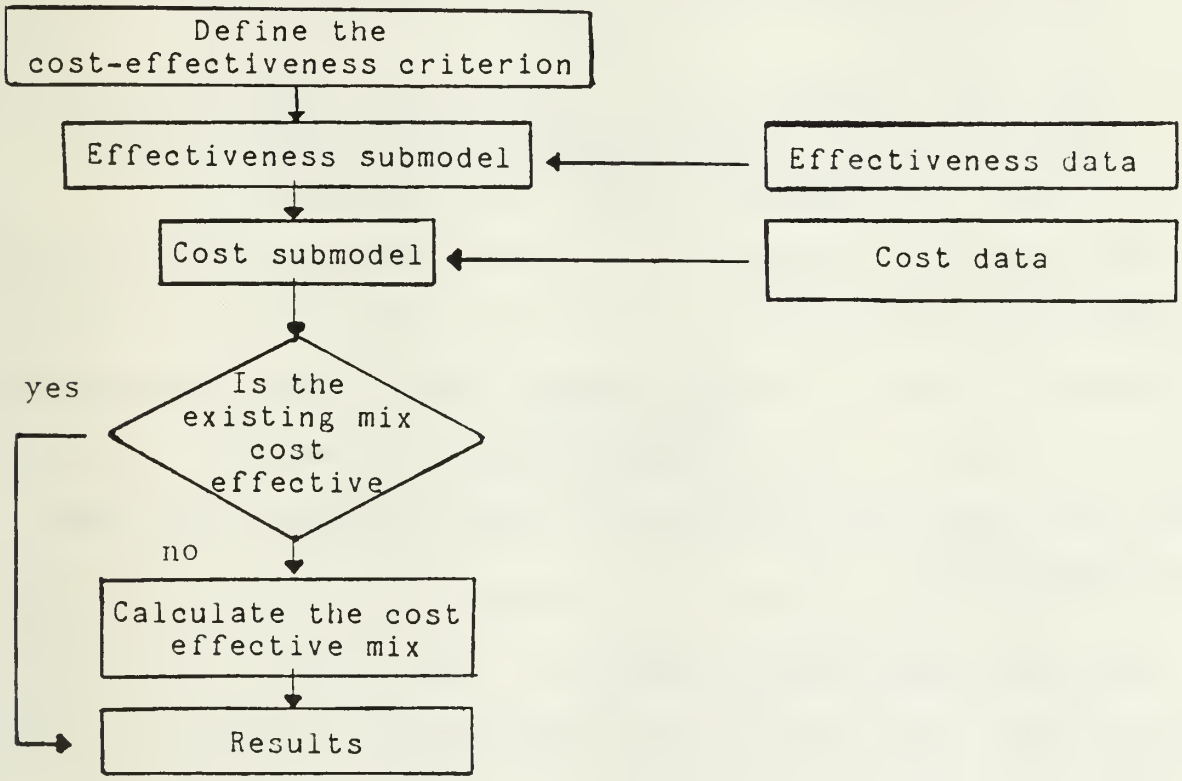


Fig. III - 1

The Training Cost Effectiveness Model - A Flow Chart

The following sections describe each step in the flow chart.

B. COST-EFFECTIVENESS CRITERION

The first step in the process of model developing was to choose between the two common criteria for cost-effective analysis. Fixing the effectiveness level and minimizing the cost was chosen

as the criterion in this model, and is due to the following reasons:

(a) The difficulties involved in quantitatively measuring the effectiveness of a military aviator. The real-world environment of the pilots is not the air-to-ground or air-to-air range, but the airspace over the enemy territories in which pure flying skills are only part of the game. We are usually able to measure air crews' performances only with respect to the "pilot" part of the term "fighter pilot," but we are rarely able to measure the "fighter" performances.

(b) The basic assumption that the existing effectiveness level of the air crew, an effectiveness that is achieved by the existing mix of flying and simulator training hours, is also the required effectiveness level.

This assumption enables us to bypass the difficulties involved in measuring effectiveness of different combinations of flying and simulator hours. We only have to find out the various combinations that give us the same effectiveness as we have now, and then compute the cost of each combination and choose the least cost combination.

C. TRAINING EFFECTIVENESS SUBMODEL

After deciding that the effectiveness level is constant in the model, we have to construct a curve which is equivalent to the isoquant curve from microeconomic theory. An isoquant is a contour line which shows all combinations of two inputs that will produce a given level of output. (See Fig. III - 2)

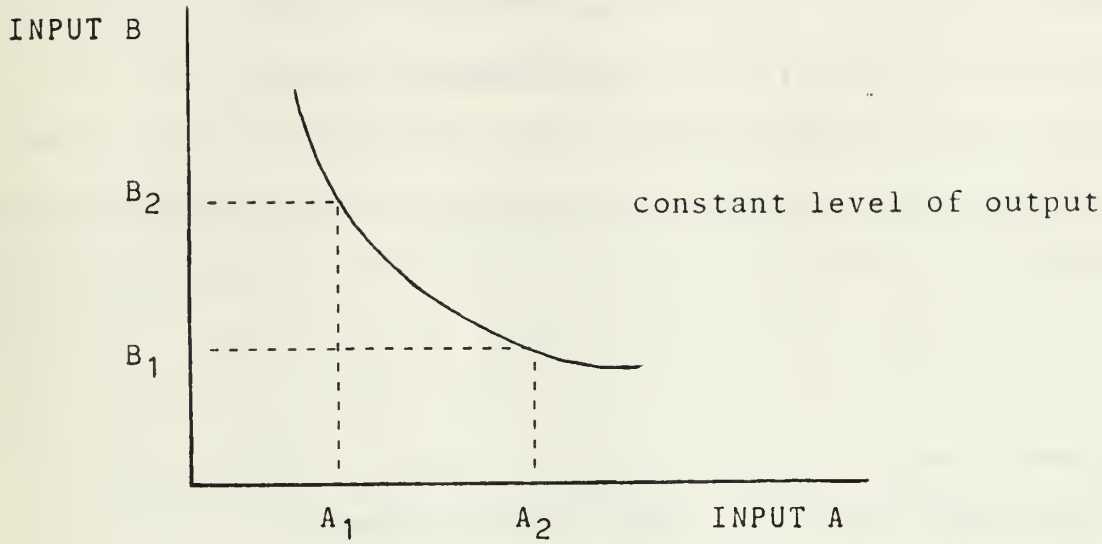


Fig. III - 2

The Isoquant Curve

The mix of input B_2 and A_1 gives the same output level of the mix B_1 and A_2. The slope of the isoquant is defined by the marginal rate of technical substitution (MRTS) which is the rate at which one input can be substituted for another while output remains constant. Thus, along the isoquant, the total differential of the output function is equal to:

$$dE = \frac{\partial E}{\partial FH} * dFH + \frac{\partial E}{\partial SH} * dSH = 0$$

In our model, output level is the effectiveness level, and the two inputs that describe the effectiveness level are yearly training flying hours per pilot and yearly simulator hours per pilot.

TRANSFER EFFECTIVENESS RATIO (TER) is the term that is used in various researches on training cost effectiveness to

describe the marginal rate of technical substitution of two training devices. Since it was first mentioned in 1971, by Roscoe and Povenmire in the Human Factor Journal [Ref. 4], the TER has been used to describe the linear relationship between the time in the trainer and the time in the operational environment. However, it is obvious that, in the case of the simulator and flying hours mix, this relationship is not linear: the first hour in the simulator is "worth" much more flying hours than the tenth hour. In microeconomic terms, a simulator hour and a flying hour are not perfect substitutions.

Figure III - 3 describes the steps in constructing the Effectiveness Isoquant.

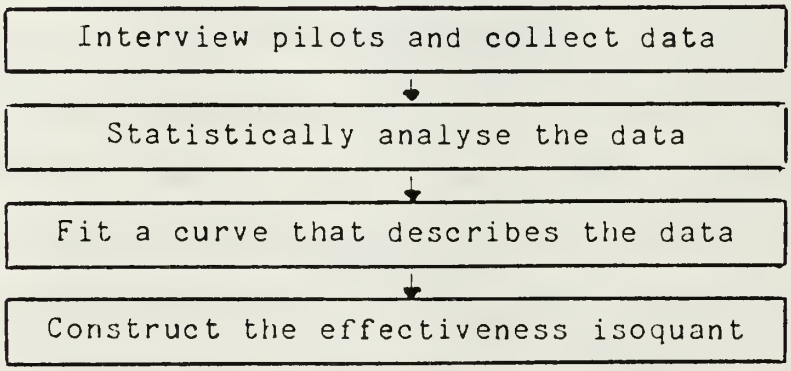


Fig. III - 3

Constructing the Effectiveness Isoquant - A Flow Chart

(a) Interview pilots and collect data - After deciding which group in the A.F. is examined by the model, pilots from this group are asked to express their opinions on the various combinations of flying and simulator hours subject to the existing level of effectiveness. Each of the pilots is given a table (Table III - 1) that contains the existing yearly mix of flying and simulator hours of himself, and a range of +20% - -20% of his yearly flying hours. The existing level of effectiveness is represented by the existing mix of flying and simulator

hours and to the range of flying hours. The pilot has to fill a range of simulator hours that will keep him on the same effectiveness level.

TABLE III - 1

TRAINING MIX - A PILOT VIEW

Yearly Flying Hours	80	85	90	95	100	105	110	115	120
Yearly Simulator Hours					6				

(b) Statistically analyze the data - Performed by computing the mean and the 95% confidence intervals to the related simulator hours to each of the flying hours data points.

$$\text{Mean } \overline{SH} = \frac{\Sigma_1^n \; SH_i}{h}$$

$$\text{Variance} = S = \sqrt{\frac{\Sigma_1^n (\overline{SH} - Sh_i)^2}{n - 1}}$$

$$\text{Upper 95\% confidence bound} = \overline{SH} \pm \frac{t^{\alpha/2} \; S}{\sqrt{n}}$$

SH - Simulator hours that are required to be used with a given number of flying hours.

n - number of pilots opinions on the required training simulator hours to the given number of flying hours.

$t_{/2}$ - is the tabulated t value cutting off a right-tail area of $^{/2}$/2, with n-1 degree of freedom.

Table III - 2 is an example of the way in which the statistical analysis on the effectiveness data has to be summarized.

TABLE III - 2

TRAINING MIX - STATISTICAL SUMMARY

Yearly Flying Hours	70	75	80	85	90	95	100	105	110	115	120
Yearly required simulator hours - average							6				
Yearly required simulator hours - upper 95% C.I.							6				
Yearly required simulator hours - lower 95% C.I.							6				

(c) Curve fitting is performed to the average, to the upper 95% and to the lower 95% C.I. The criterion that is used to fit the curve is the least R square criterion and the basic function that describes the curve is the power function $Y = ax^b$. The power function makes the computations relatively easy by linearization of the function to the form of $\log Y = \log a + b * \log x$, and then using the linear regression as a model to compute and R square.

(d) Construct the effectiveness isoquant - The three curves that have already been fitted are constructed as shown in Fig. III - 4.

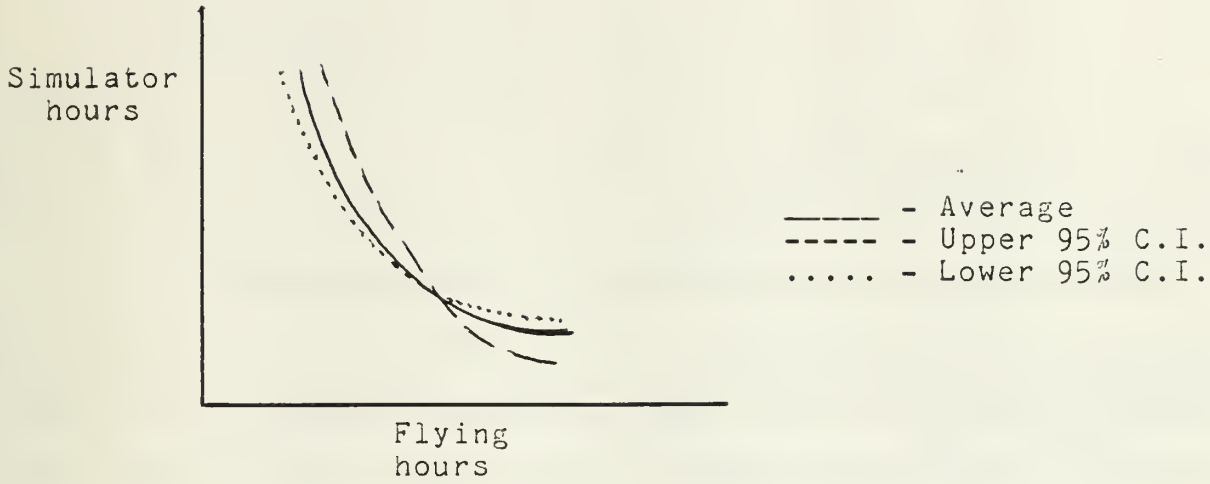


Fig. III - 4

The Effectiveness Isoquants

The slope of the curves represents various ranges of the Transfer Effectiveness Ratio. In order to stay on the "safe side," only the upper 95% C.I. will be used in the rest of the analysis. This is a way to compensate the weakness of the TER computations, a weakness that is rooted in the absence of empirical data.

D. TRAINING COST SUBMODEL

The cost submodel has the function of determining the cost of training along the 95% upper C.I. effectiveness isoquant that has been constructed in the effectiveness submodel. For our purposes, the cost of training is a function of the average cost of flying hour, average cost of a simulator hour, yearly average flying hours per pilot, yearly average simulator hours per pilot, and the number of pilots in the groups under examination.

Figure III - 5 describes the cost submodel steps.

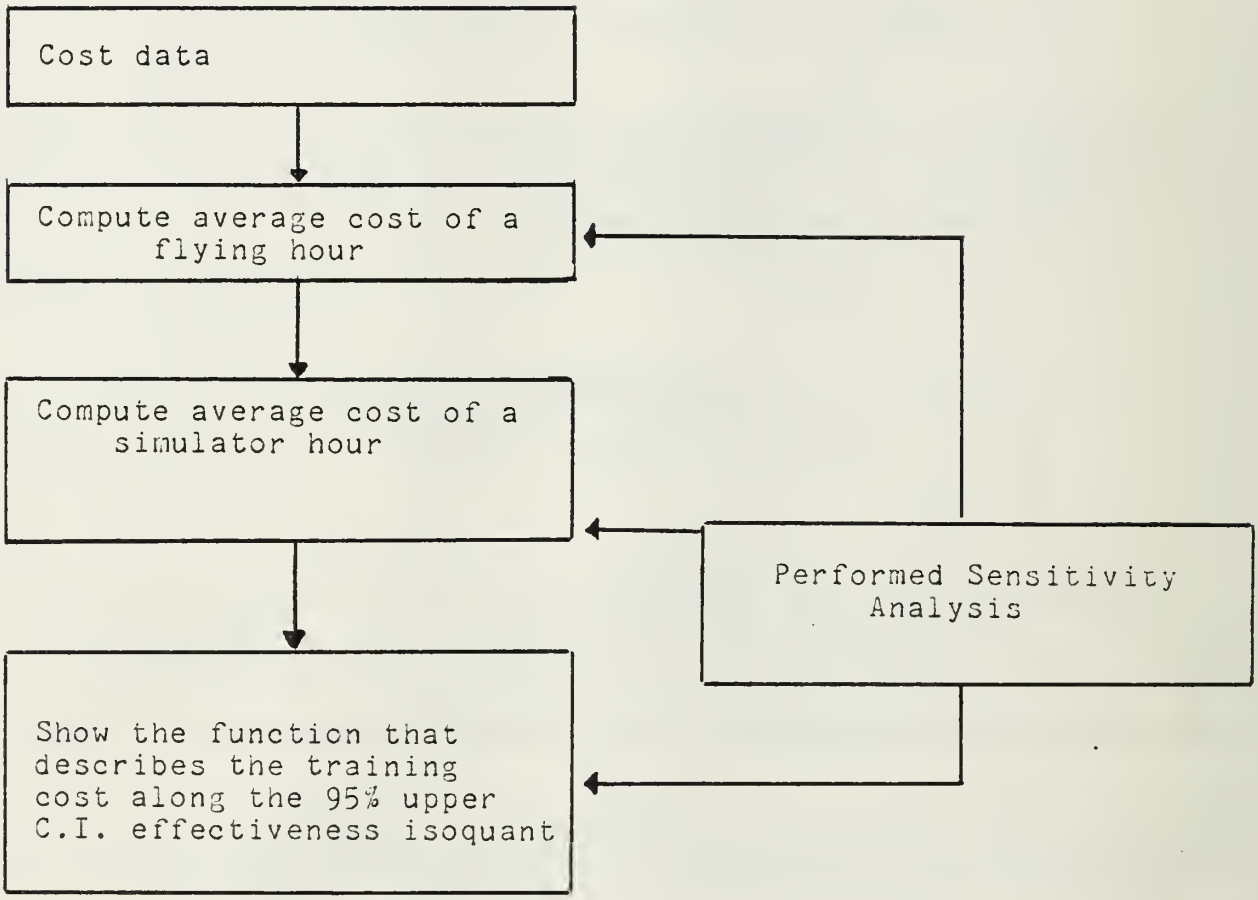


Fig. III - 5

Cost Submodel - A Flow Chart

(a) Cost data - The cost data which is used in the I.A.F. is limited to a constant average flying hour cost and to no data on the average cost of a simulator hour except from those groups that get their simulator training outside the country.

(b) Average cost of a flying hour - As mentioned above, the existing way of computing the average cost of a flying hour implies a constant average cost, which is a reasonable assumption while considering a short range of total flying hours. Built in our model, a wide range of total flying hours is considered, so a different model of computing the average cost of a flying hour is needed: a model in which the average cost varies over the range of total flying hours. Instead of using a model which is not in existence, a sensitivity analysis is performed in our cost submodel on the existing data. The technique that is used in the sensitivity analysis is based on the learning curve theory: each time the total flying hours we produced is doubled, the cost per flying hour is reduced to a constant percentage of its previous cost. The formulation of the learning curve theory results in a power function and the implementation of this function for our sensitivity analysis results in the following equation:

$$A_c = \frac{C * X^{-b}}{FH^{-b}}$$

A_c - The average cost of a flying hour related to a total of X flying hours.

C - The existing cost of a flying hour which is based on the data

FH - The total existing yearly flying hours in the examined group

b - Is the power term that describes the percentage reduction in the average cost of a flying hour by doubling the total flying hours.

$$b = \frac{\log .\% \text{ of cost reduction}}{\log 2}$$

The following example demonstrates the way of performing the sensitivity analysis on the cost computation:

(1) The existing cost of a flying hour (C) = $5000.

(2) Total yearly flying hours in the examined group (FH) = 2000 hours.

(3) Estimated percentage average cost reduction while doubling total flying hours = 10%.

(4) Total yearly flying hours that we wish to compute the related average cost of a flying hour (X) = 1700.

$$b = \frac{\log .9}{\log .2} = .152$$

$$A_c = \frac{(5000)\ (1700^{-.152})}{2000^{-.152}} = \$5125.05$$

(5) Conclusion - By decreasing the total flying hours from 2000 hours per year to 1700 hours per year, the average cost of a flying hour is changed from $5000 to $5125.05.

(c) <u>Average cost of a simulator hour</u> - The same technique that was described in the sensitivity analysis of the average cost of a flying hour is used for the sensitivity analysis of the average cost of a simulator hour. In this case, due to the small numbers of total simulator hours in the present, and due to the fact that the cost data that we have is based only on the cost of training outside the country, it is assumed that any future combination of training hours will cause a reduction in the average cost of a simulator hour. This assumption leads to the following equation:

$$A_c = C * X^{-b}$$

A_c = The average cost of a simulator hour relates to a total of X total simulator hours.

C = The average constant cost of a simulator hour in the present.

b = The power term that expresses the percentage reduction in the average cost of a simulator hour while doubling total yearly simulator hours.

The following example demonstrates the way of performing the sensitivity analysis on the simulator average cost computation:

(1) Existing cost of a simulator hour (C) = $500.

(2) The estimated percentage reduction in the average cost of a simulator hour while doubling total simulator hours - 5%.

$$b = \frac{\log .95}{\log 2} = -.074$$

(3) Total yearly simulator hours in the examined training mix (X) = 1000.

$$A_c = (500) * 1000^{-.074} = \$299.89$$

E. TOTAL TRAINING COST

The following equation describes the total yearly training cost:

$$C_t = (X_{fh} * A_{cfh} + X_{sh} * A_{csh}) P$$

C_t - Total yearly cost of training of the examined training mix.

X_{fh} - Yearly flying hours per pilot in the examined training mix.

X_{sh} - Yearly simulator hours in the examined training mix.

A_{cfh}- Average cost of a flying hour in the examined training mix.

P - Number of pilots in the group.

The final results of the cost submodel is a graph that shows the relation between the mix of training to its cost. The number of curves in the graph are determined by the number of sensitivity analyses that we want to perform. (See Fig. III - 6)

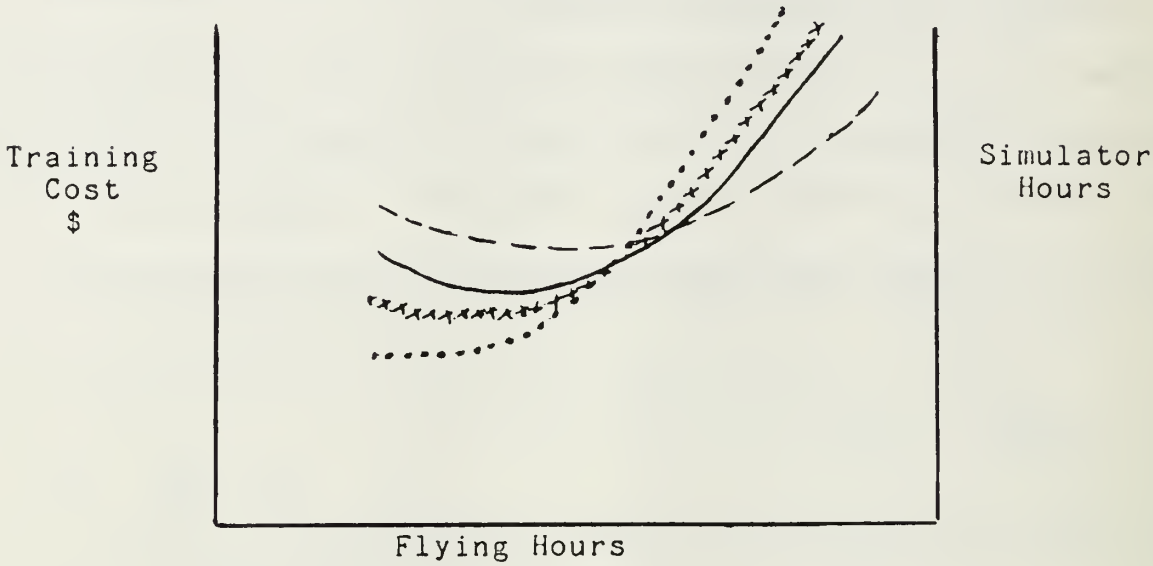


Fig. III - 6

Training Cost Curves

Fig. III - 6 is an example of 4 different cost curves based on the following sensitivity analysis:

(a) _____ Constant average cost of a flying hour and a 95% learning curve in the average cost of a simulator hour.

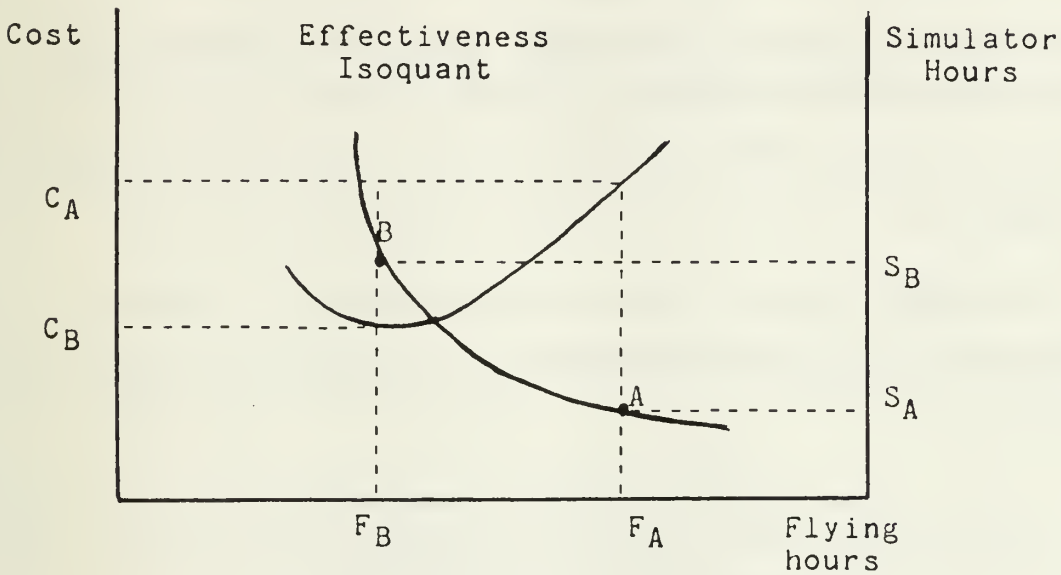
(b) ----- Constant average cost of a simulator hour and 90% learning curve in the average cost of a flying hour.

(c) ***** Constant average costs of a flying and a simulator hour.

(d) ..... 95% learning curve in the average cost of a simulato hour and 90% learning curve in the average cost of a flying hour.

F. IS THE EXISTING TRAINING MIX COST EFFECTIVE?

Relating the effectiveness isoquant and the cost curves gives us the answer to our first question - "Is the existing training mix cost effective?"



(a) Point A represents the existing training mix.

(b) Point C_A represents the total cost of the existing training mix.

(c) Point B represents the least cost feasible mix of training.

(d) Point C_B represents the total cost of B mix.

(e) $C_A - C_B$ - is the dollar value of the difference between the existing training mix and the cost-effective training mix.

(f) $\left(\frac{C_A - C_B}{C_B}\right) 100$ - is the percentage expression to the existence level of cost effectiveness.

G. THE COST EFFECTIVE TRAINING MIX

The final step in the model is defining the cost-effective mix of training in the examined group. Although we are using the least cost training mix for a given constant effectiveness level as a criterion for the analysis, it is unrealistic to make the least cost mix as the actual mix. The actual mix of training is subject to various constraints which make the linear programming technique as a way to arrive at the cost-effective mix solution.

The flow chart in Fig. III - 8 illustrates the steps in the process of solving the cost-effective mix by linear programming techniques.

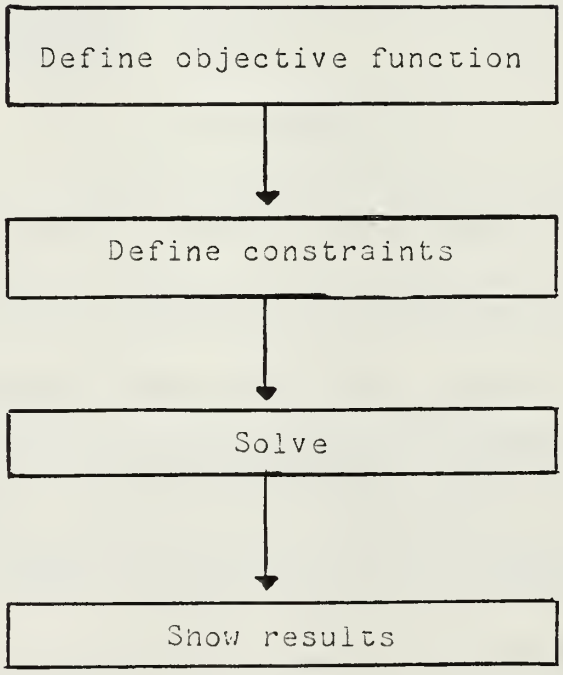


Fig. III - 8

Solving the Cost Effective Training Mix - A Flow Chart

1. The objective function in our analysis is:

   Minimize $C_t = (X_{fh} * A_{cfh} + X_{sh} * A_{cfh})\ P$

   C_t - Total yearly cost of training

   X_{fh} - Yearly flying hours per pilot

   A_{cfh}- Average cost of a flying hour

   X_{sh} - Yearly simulator hours per pilot as it has already been determined by the effectiveness isoquant function

   A_{ssh}- Average cost of a simulator hour

2. The constraints are usually defined by management authorities. For example:

   - Number of pilot (P) is constant and not subject to change.

   - Yearly flying hours per pilot (Xfh) $\geq$ yearly simulator hours per pilot (X_{sh})

   - Total increasing in training $\leq$ 50%

3. Solving the problem is done by linear programming computerized packages.

Depending upon the number of sensitivity analyses that have been performed along the analysis, we will get not a single solution but a range of cost effective and feasible solutions.

The next chapter is dedicated to illustrate three examples of using the model to analyze training cost effectiveness in three of the I.A.F. communities.

IV. TRAINING COST EFFECTIVENESS ANALYSIS - AN ILLUSTRATION

A. GENERAL

In this chapter, the training cost effectiveness model that was described in the previous chapter will be illustrated. For the purposes of this illustration, 3 groups of the I.A.F. will be analyzed and compared:

(a) The training cost effectiveness of the Jet pilot.

(b) The training cost effectiveness of the Helicopter pilot.

(c) The training cost effectiveness of the Transport pilot.

By examining those groups, a low level of resolution and an aggregate model is implied which is not the case when implementi the model in reality. In reality, more specific training groups have to be examined in order to get practical results. The unclassified restrictions of this paper prevent an illustration of the model in a higher resolution, so the numbers along the analysis and the results of each of the analyses have to be considered as a means to illustrate the use of the model and as a low resolution picture of the training cost effectiveness in each of the three groups. The unclassified restrictions of the paper prevent the author also, from detailing numbers of pilots, so the illustrated examples will stay on the level of an individual pilot.

Each of the following sections is dedicated to each of the three groups. The last section will summarize the results.

B. TRAINING COST EFFECTIVENESS - THE JET PILOT

Twenty jet pilots were asked to express their view on the Transfer Effectiveness Ratio of using simulators in their group without changing the effectiveness level. The existing effectiveness level is represented by an average of 100 yearly flying hours and 7 yearly simulator hours per pilot. Each of the pilots had to consider 4 levels of flying hours - 80, 90, 110, and 120. The summarized results are shown in Table IV - 1.

TABLE IV - 1

TRANSFER EFFECTIVENESS RATIO - JETS

Flying hours / Simulator hours	80	90	100	110	120
Average	124.00	48.75	7.00	4.80	3.45
Upper 95% C.I.	146.23	60.44	7.00	4.29	2.94
Lower 95% C.I.	101.77	37.06	7.00	5.32	3.96

Based on the above statistics, 3 effectiveness isoquants were fitted and are shown in Fig. IV - 1.

1. Effectiveness isoquant that is based on the average Transfer Effectiveness Ratio:

   $SH = \text{antilog } 20.1 * FH^{-9.47}$

   $R^2 = 93.2\%$

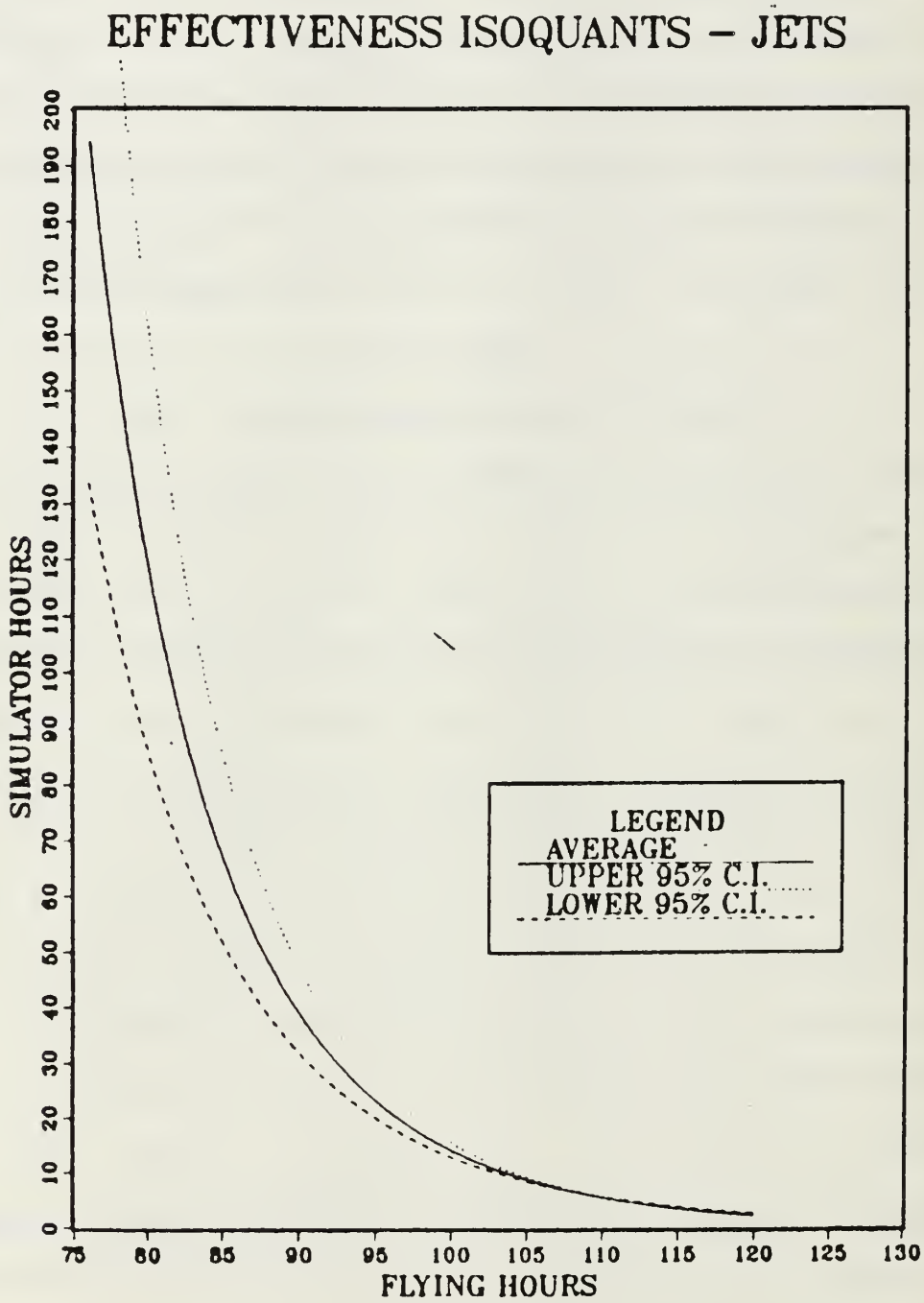


Figure IV - 1
The Effectiveness Isoquants - Jets

SH - yearly simulator hours per pilot

FH - yearly flying hours per pilot

2. Effectiveness isoquant that is based on the upper 95% C.I. Transfer Effectiveness Ratio:

$SH = \text{antilog } 22 * FH^{-10.4}$

$R^2 = 93.6\%$

3. Effectiveness isoquant that is based on the lower 95% C.I. Transfer Effectiveness Ratio:

$SH = \text{antilog } 18 * FH^{-8.44}$

The upper 95% C.I. effectiveness isoquant is used in the rest of the analysis.

The following average costs are used in the computation of total cost of training:

(a) Constant average cost of a jet flying hour = $8567.

(b) Average cost of a flying hour with a learning curve of 20%.

(c) Constant average cost of a jet simulator hour = $564.

(d) Average cost of a jet simulator hour with a learning curve of 90%.

Fig. IV - 2 shows four different cost curves based on the above methods of computing average training hour cost and how they relate to the yearly flying hours that are implied by the effectiveness isoquant.

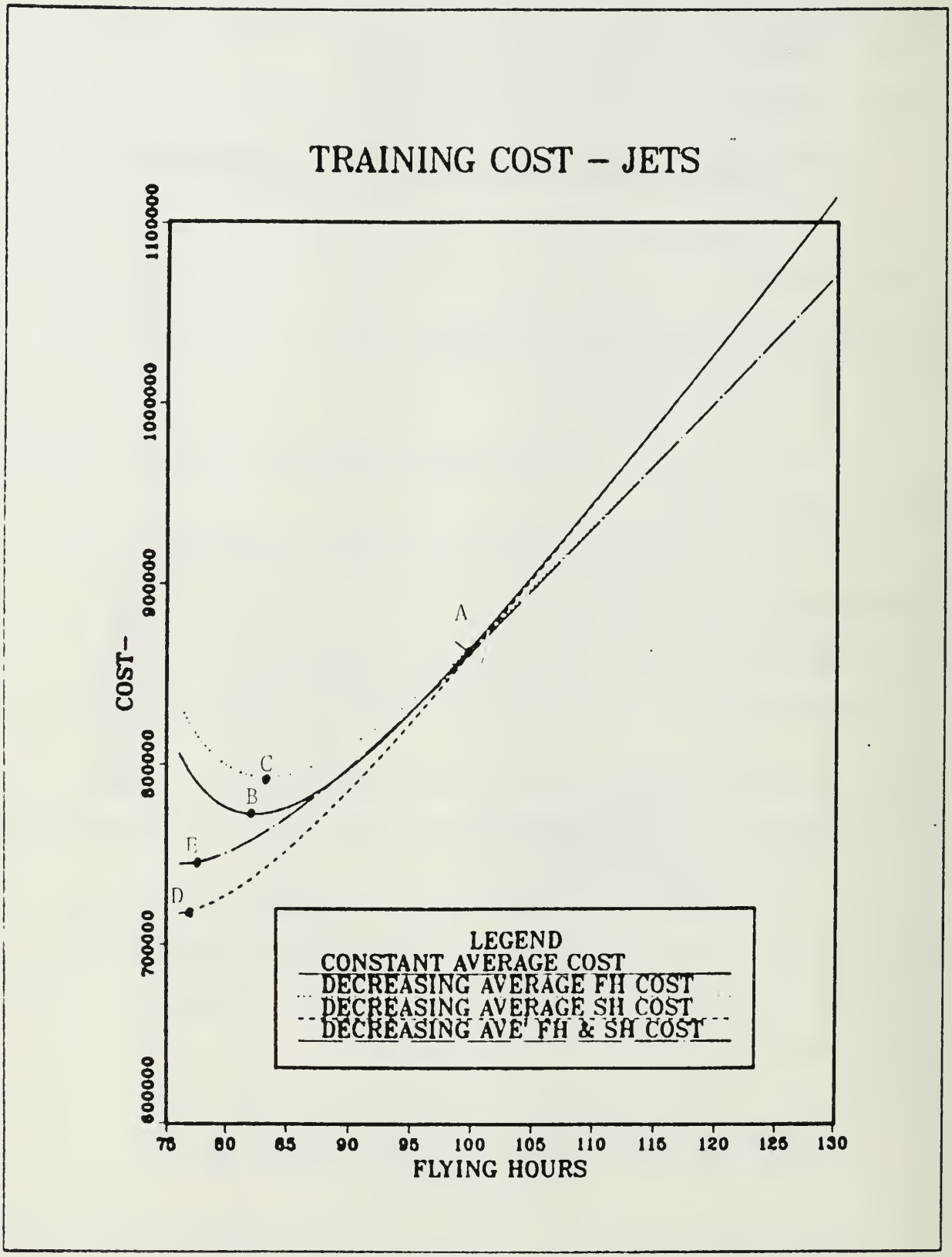


Figure IV - 2
The Training Cost Curves - Jets

Point A represents the existing yearly cost of training a jet pilot.

$$C = 100 * 8567 + 7 * 564 = \$860,648$$

Table IV - 2 is a summary of points B-E on the graph.

TABLE IV - 2

COST EFFECTIVENESS - PRESENT JETS TRAINING MIX

Point	Method of Computing Average Cost		Least Cost Mix		Cost of Training	Cost Effective-ness
	Flying Hour	Simulator Hour	Flying Hours	Simul. Hours		
B	constant	constant	82	124	$772,430	-$88,218
C	90% learning curve	constant	83	110	$793,528	-$67,120
D	constant	90% learning curve	77	240	$718,502	-$142,146
E	90% learning curve	90% learning curve	78	210	$746,488	-$114,160

The conclusion at this stage of the analysis is that, without considering any constraints, the jet pilot training is not cost effective by the range of $67,120 - $142,146, which is 8%-16% of the present cost of training.

Before concluding on the cost-effective mix and what can be really saved, two constraints will be presented as an example:

(a) Total yearly simulator hours cannot exceed total yearly flying hours.

(b) Total increase in yearly training hours cannot exceed 50% of the present training hours.

Solving the problem of the least cost feasible training mix by linear programming techniques leads us to conclude that 87 flying hours and 67 simulator hours is the most cost effective training mix. Table IV - 3 summarizes the cost-effectiveness meaning of the training mix.

TABLE IV - 3

THE COST EFFECTIVE TRAINING MIX - JETS

Method of Computing Average Cost		Least Cost Feasable Mix		Cost of Training	Saving	
Flying Hour	Simulator Hour	Flying Hours	Simulator Hours		$	%
constant	constant	87	67	$783,117	$77,531	9%
90% learning curve	constant	87	67	$799,062	$61,586	7.2%
constant	90% learning curve	87	67	$765,272	$95,376	11%
90% learning curve	90% learning curve	87	67	$781,217	$79,431	9.2%

To conclude, $61,586 - $95,376, which is 7.2%-11% from the present cost of training, can be saved from the cost of training an individual jet pilot by changing the training mix from 100 flying hours and 7 simulator hours to 87 flying hours and 67 simulator hours.

C. TRAINING COST EFFECTIVENESS - THE HELICOPTER PILOT

Twenty helicopter pilots were asked to express their views on the Transfer Effectiveness Ratio of using simulators in their group and without changing the existing training effectiveness. The existing effectiveness is represented by 80 yearly training flying hours and 20 yearly simulator hours on the average. Each of the pilots had to consider four ranges of flying hours - 60, 70, 90, and 100. The results are summarized in Table IV - 4.

TABLE IV - 4

TRANSFER EFFECTIVENESS RATIO - HELICOPTERS

Flying hours / Simulator hours	60	70	80	90	100
Average	158.25	74.25	20.00	13.30	10.20
Upper 95% C.I.	194.46	87.93	20.00	12.44	9.26
Lower 95% C.I.	122.06	60.57	20.00	14.16	11.19

Based on the above statistics, three effectiveness isoquants were fitted and are shown in Fig. IV - 3:

1. The effectiveness isoquant that is based on the average Transfer Effectiveness Ratio:

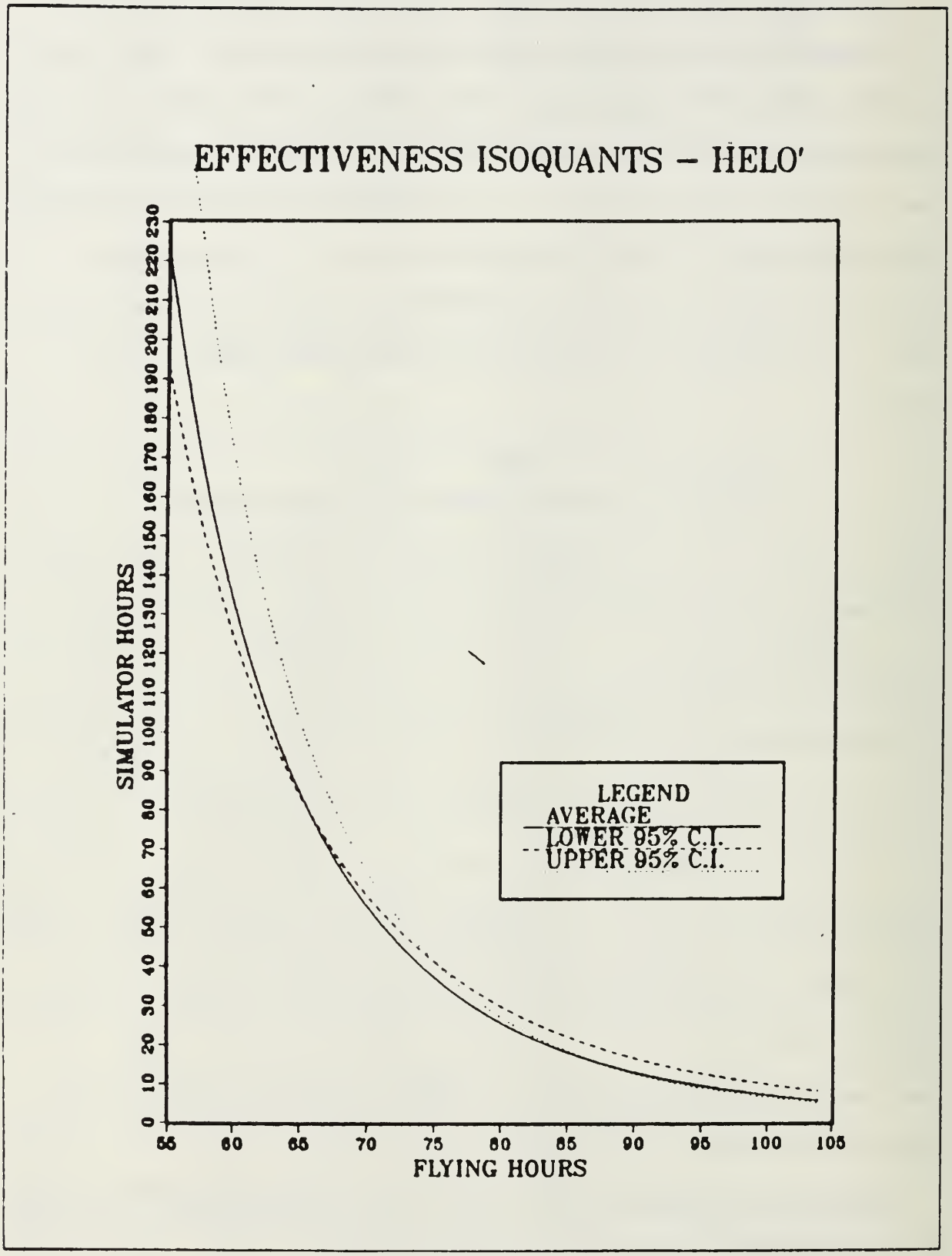


Figure IV - 3
The Effectiveness Isoquants - Helicopters

$SH = \text{antilog } 12.3 * FH^{-5.72}$

$R^2 = 95.7\%$

SH - Yearly simulator hours per pilot

FH - Yearly flying hours per pilot

2. Effectiveness isoquant that is based on the upper 95% C.I. Transfer Effectiveness Ratio:

$SH = \text{antilog } 13.6 * FH^{-6.39}$

$R^2 = 95.8\%$

3. Effectiveness isoquant that is based on the lower 95% C.I. Transfer Effectiveness Ratio:

$SH = \text{antilog } 10.9 * FH^{-4.95}$

$R^2 = 95.9\%$

The upper 95% C.I. isoquant is used in the rest of the analysis. The following average costs are used in the total cost of training submodel:

(a) Constant average cost of a helicopter hour - $2200.

(b) Average cost of a flying hour with a learning curve of 90%.

(c) Constant average cost of a helicopter simulator hour - $562.

(d) Average cost of a helicopter simulator hour with a learning curve of 90%.

Fig IV - 4 shows four different cost curves based on the above methods of computing average costs and how they relate to the yearly flying hours that are implied by the effectiveness isoquant.

Point A on the graph represents the existing yearly cost of training a helicopter pilot:

$$C = 80 * 2200 + 20 * 562 = \$187,240$$

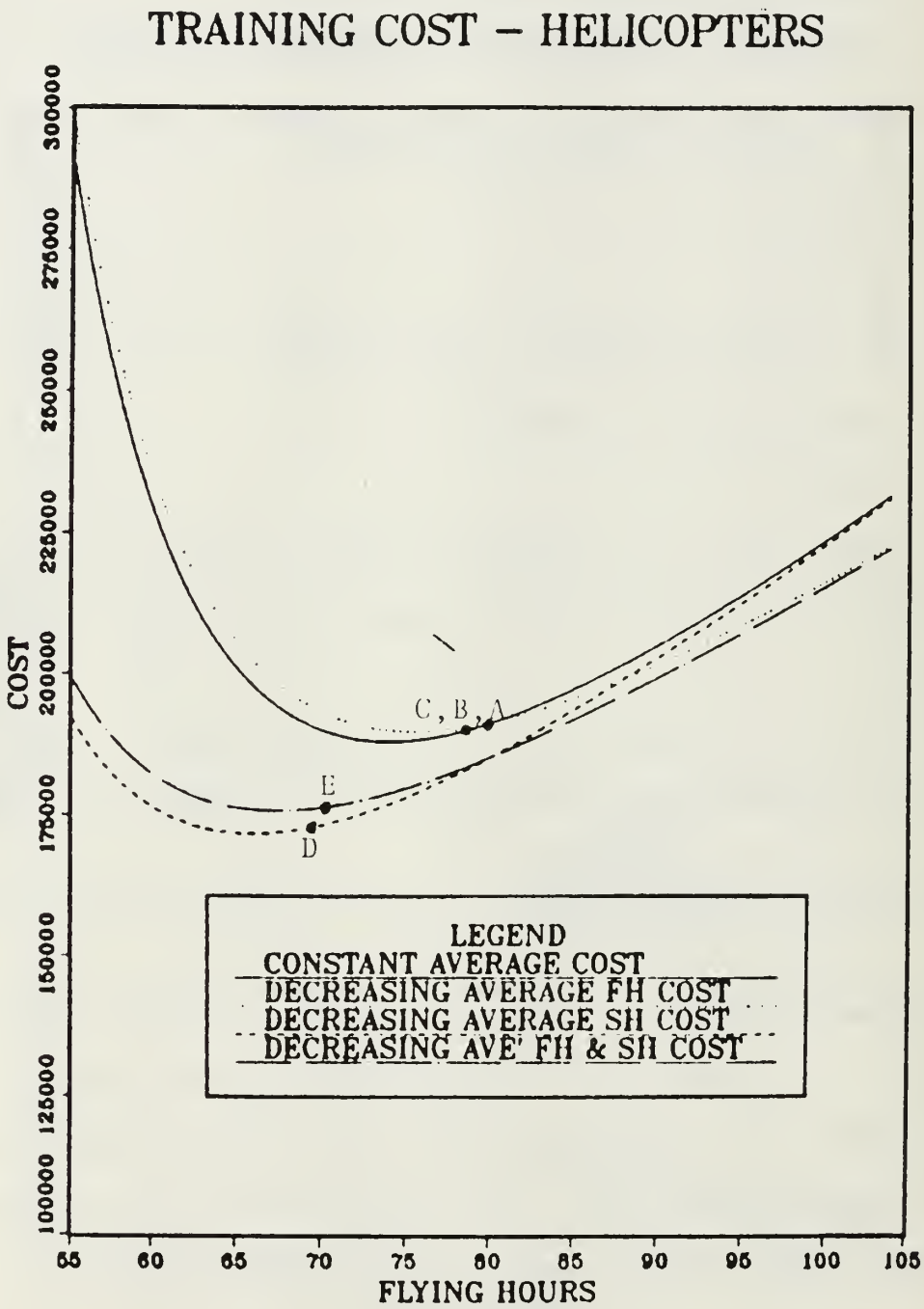


Figure IV - 4
Training Cost Curves - Helicopters

Table IV - 5 summarizes the cost effectiveness in the helicopter community, which is represented by points B-E on the graph.

TABLE IV - 5

COST EFFECTIVENESS - PRESENT HELICOPTERS TRAINING MIX

Point	Method of Computing Average Cost		Least Cost Mix		Cost of Training	Cost Effectiveness
	Flying Hour	Simulator Hour	Flying Hours	Simul. Hours		
B	constant	constant	80	20	$187,240	1
C	90% learning curve	constant	80	20	$187,240	1
D	constant	90% learning curve	71	58	$173,784	-$13,456
E	90% learning curve	90% learning curve	72	53	$177,247	-$9,993

The conclusion at this stage of the analysis is that the present mix of training in the helicopter community is cost effective, and only by introducing a 90% learning curve in the cost of an average simulator hour, $9,993 - $13,456, which is 5.3% - 7.2% of the present cost of training can be saved.

D. TRAINING COST EFFECTIVENESS - THE TRANSPORT PILOT

Eighteen transport pilots were asked to express their views on the Transfer Effectiveness Ratio of using simulators in their

group without changing the existing training effectiveness. The existing effectiveness level is represented by an average of 50 yearly flying hours and six yearly simulator hours per pilot. Each of the pilots had to consider four levels of yearly flying hours - 40, 45, 55, and 60. The results are summarized in Table IV - 6.

TABLE IV - 6

TRANSFER EFFECTIVENESS RATIO - TRANSPORTS

Flying hours / Simulator hours	40	45	50	55	60
Average	35.25	15.45	6.00	3.50	2.35
Upper 95% confidence bound	42.67	17.75	6.00	2.20	2.00
Lower 95% confidence bound	27.83	13.33	6.00	4.09	2.70

Based on the above statistics, three effectiveness isoquants were fitted and are shown in Fig. IV - 5:

1. Effectiveness isoquant based on the average Transfer Effectiveness Ratio:

   $SH = \text{antilog } 12.5 * FH^{-6.86}$

   $R^2 = 98.8\%$

   SH = Yearly simulator hours per pilot

   FH = Yearly flying hours per pilot

2. Effectiveness isoquant that is based on the upper 95% confidence interval Transfer Effectiveness Ratio:

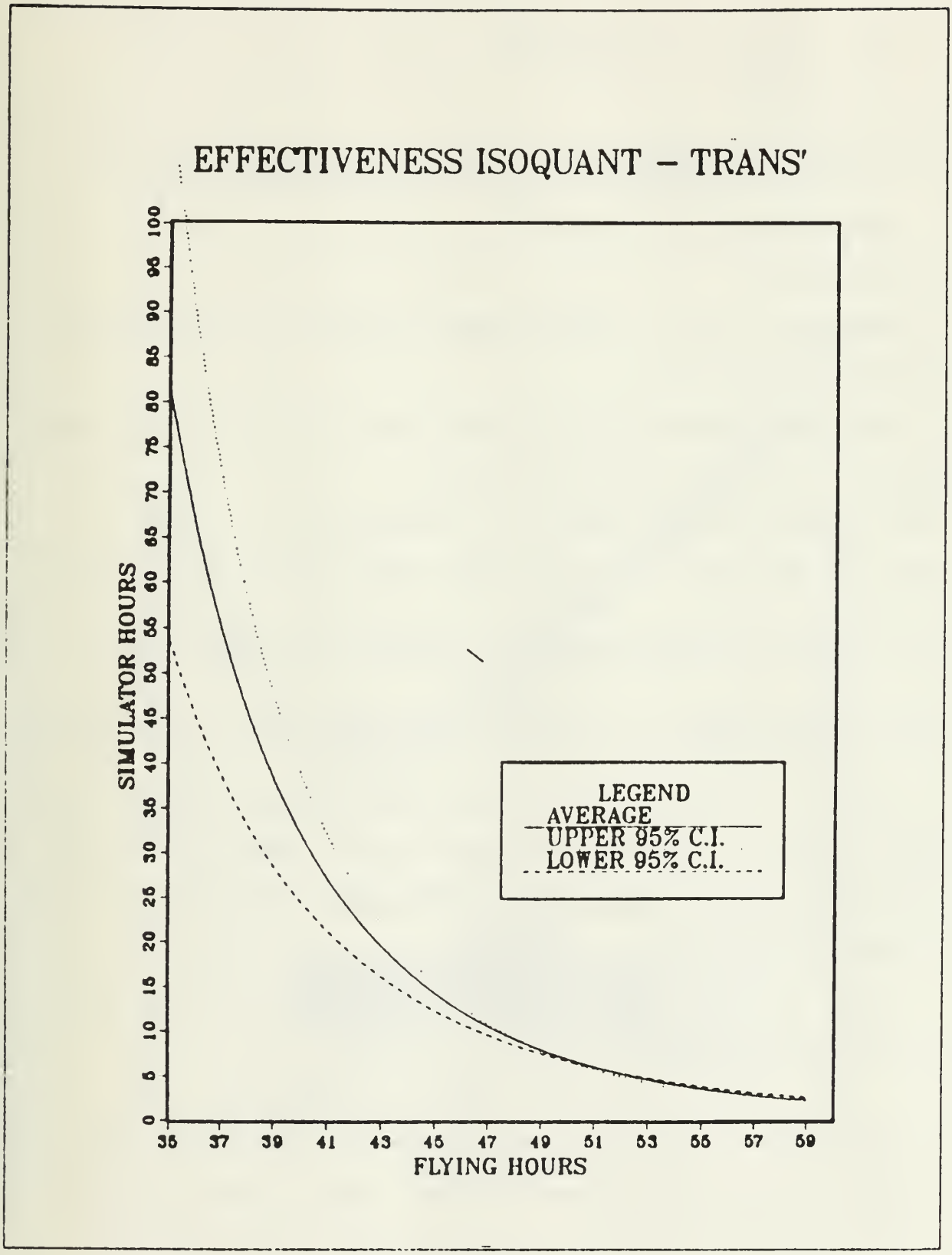


Figure IV - 5
The Effectiveness Isoquants - Transporters

$SH = \text{antilog } 14.2 * FH^{-7.87}$

$R = 98.7\%$

3. Effectiveness isoquant that is based on the lower 95% confidence interval Transfer Effectiveness ratio:

$SH = \text{antilog } 10.7 * FH^{-5.81}$

$R^2 = 98.8\%$

The upper 95% C.I. effectiveness isoquant is used in the rest of the analysis.

The following average costs are used in the submodel computations of the total cost of training:

(a) Constant average cost of a transport hour - $3140.

(b) Average cost of a flying hour with a learning curve of 90%.

(c) Constant average cost of a transport simulator hour = $550.

(d) Average cost of a transport simulator hour with a learning curve of 90%.

Fig. IV - 6 shows four different cost curves based on the above methods of computing average training hour cost and how they relate to the yearly flying hours that are implied by the effectiveness isoquant.

Point A on the graph represents the existing yearly cost of training a transport pilot:

$$C = 3140 * 50 + 550 * 6 = \$160,300$$

Table IV - 7 summarizes the differences between the existing training mix and four points of least cost training mixes (B-E).

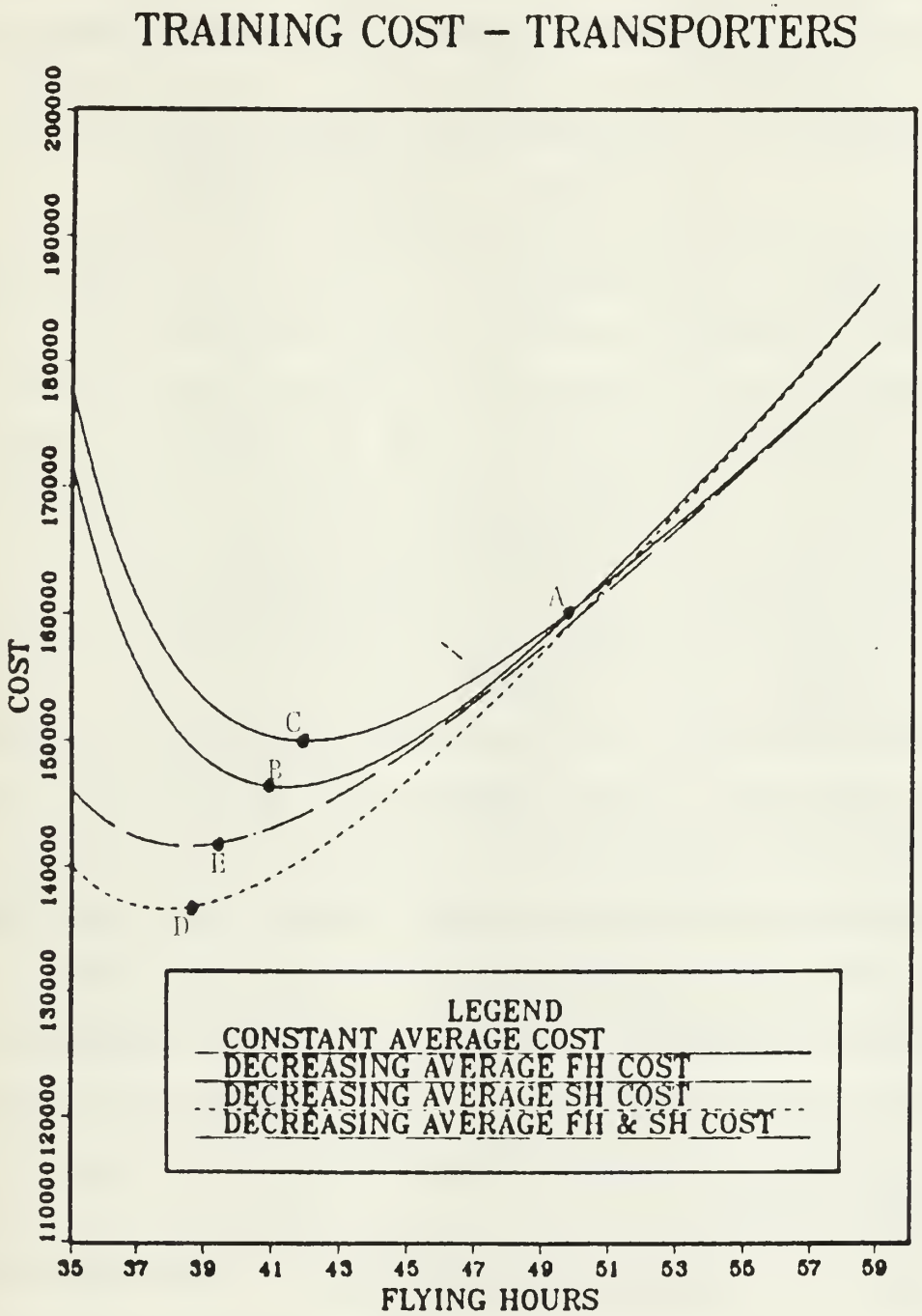


Figure IV - 6
The Training Cost Curves - Transporters

TABLE IV -7

COST EFFECTIVENESS - PRESENT TRANSPORTER MIX

Point	Method of Computing Average Cost		Least Cost Mix		Cost of Training	Cost Effec-tiveness
	Flying Hour	Simulator Hour	Flying Hours	Simul. Hours		
B	constant	constant	41	32	$146,340	-$13,960
C	90% learning curve	constant	42	26	$149,722	-$10,578
D	constant	90% learning curve	39	48	$137,117	-$23,783
E	90% learning curve	90% learning curve	40	39	$142,224	-$18,076

The conclusion, at this stage of the analysis, is that without considering any constraints, the transport pilot training is not cost effective by the range of $10,578 - $23,183, which is 6.6% - 14.5% of the present cost of training.

Before concluding on the cost-effective mix and what can be really saved, two constraints will be introduced as an example:

(a) Total yearly simulator hours cannot exceed total yearly flying hours.

(b) Total increase in yearly training hours cannot exceed 50% of the present training hours.

Solving the problem of the least cost feasible training mix by linear programming techniques leads us to the conclusions that are summarized in Table IV - 8.

TABLE IV - 8

THE COST EFFECTIVE TRAINING MIX - TRANSPORTER PILOT

Method of Computing Average Cost		Least Cost Feasible Mix		Cost of Training	Saving	
Flying Hour	Simulator Hour	Flying Hours	Simulator Hours		$	%
constant	constant	41	32	$146,340	$13,960	8.7%
90% learning curve	constant	42	26	$149,722	$10,578	6.6%
constant	90% learning curve	41	32	$139,133	$21,167	13.2%
90% learning curve	90% learning curve	40	39	$142,224	$18,076	11.3%

According to the results shown in Table IV - 8, $10,578 $21,167, which is 6.6$-13.2% of the training cost, can be saved from the training cost of an individual transport pilot by changing the existing training mix of 50 flying hours and 6 simulator hours to a training mix of 40 - 42 flying hours and 26 - 39 simulator hours, depending on the method of computing the average training hour cost.

E. SUMMARY

Comparing the cost effectiveness results in the three groups leads to the following conclusions:

1. The jet group is the least cost effective group. Some $61,586 - $95,376, which is 7.2% - 11% of the present cost of training, can be saved from the cost of training an indi vidual jet pilot by changing the training mix from 100 flying hours and 7 simulator hours to 87 flying hours and 67 simulator hours.

   Even by introducing more conservative constraints of no more than 25% increase in total training hours, a saving potential of $46,197 - $80,732, which is 5.4% - 9.4% from the cost of an individual pilot training, still exists.

2. The transport group has the potential of saving $10,578 - $21,167, which is 6.6% - 13.2% of the yearly cost of training an individual pilot. That can be achieved by changing the present average mix of 50 flying hours and 6 simulator hours to a yearly training mix of 40 - 42 flying hours and 26 - 39 simulator hours.

3. The helicopter community is cost effective in the training mix. Only if a 90% learning curve can be introduced in the future, a saving of $9,993-$13,456, which is 5.3%-7.2% of the yearly training cost of an individual pilot can be achieved by introducing a new mix of training. In this case, the existing mix of 80 flying hours and 20 simulator hours has to be changed to 71-72 flying hours and 53-58 simulator hours.

In order to complete the comparison among the three groups, the potential dollar savings should be multiplied by the number of pilots in each group. Although the author is prevented from doing it in this unclassified paper, it is obvious that the order of the potential savings is not going to be changed, and the jet community has the greatest potential for cost savings.

V. CONCLUSIONS AND RECOMMENDATIONS

As mentioned in the first chapter, the goals of this thesis are two:

a. To construct a model that can be used to analyze the air crews training flying, and simulator hours cost effectiveness mix in the I.A.F.

b. To illustrate the use of the model, as an example in the Jet, Helicopter, and Transport communities in the I.A.F. The illustration was made by examining the following questions in each group:

   (1) Is the existing mix of training cost effective?

   (2) What is the potential cost-effective mix in each of the groups?

Along the way in developing the model, two important factors have been considered; the effectiveness of the training mix and the cost of training. The methods of measuring these two factors that are the foundation of the cost-effectiveness model are very weak and some ways to strengthen those methods were considered.

The existing ways of measuring air-crews training effectiveness are limited mainly to the peace-time environment and, as a result, to the technical skills of the pilot and not to his actual performance and quality as a fighter pilot. Hence, the pilots' knowledge and experience were chosen as a way to measure training effectiveness. They were asked to express their opinions on the various training combinations that have the potential of keeping the existing level of training effectiveness. It is recommended that this measuring tool be strengthened and updated by a long-term experiment with a small representative group of pilots.

The existing way of measuring an average cost of a flying hour implies a constant average cost. It is obvious that, over a wide range of flying hours, the average cost of a flying hours is changed. In order to reduce the sensitivity of our model to the change of the average cost of a flying hour, the learning curve theory has been introduced and used in the examples. It is recommended to develop a more realistic flying hour cost estimation model, one that can strengthen this model and, probably, can be used to update various other cost effectiveness models.

There is no model to compute the cost of simulator training hours. The dollar values that were used in our model is based on the cost of simulator training outside the country, which are the only cost estimates that are in existence in the I.A.F. As was demonstrated in the example analysis, and will be summarized later, the average cost of a simulator hour is the most influential factor in the model. It is recommended that a training simulator hour cost estimation model be developed before going into a training mix cost effectiveness analysis.

To illustrate the use of the model, three groups were chosen - the Jets, Helicopters, and the Transports. For reasons of classification, the illustration was limited to the average pilot from each of the groups. The term "average pilot," in this case, is a way of considering various levels of experience, status, and type of aircraft as one level, a level that gets constant yearly flying and simulator hours, and has a yearly fixed cost. While doing the analysis this way may prevent us from directly implementing the results, it does give us a clear

and general picture of the training cost effectiveness, differences among the three groups, and the dominant factors in the analysis.

Table V - 1 summarizes the main results in the demonstrated analysis.

TABLE V - 1

DEMONSTRATE TRAINING COST EFFECTIVENESS ANALYSIS - RESULTS

Group	Existing Training Mix		Existing Cost of Training A Pilot	Cost Effective Mix		Potential Cost	Potential Saving	
	Flying Hours	Simul. Hours		Flying Hours	Simul. Hours		$	%
Jets	100	6	$860,648	87	67	$765,272-$799,062	$61,586-$95,376	7.2-11%
Heli-copters	80	20	$187,240	80-71	20-58	$187,240-$173,784	$0-$13,456	0%-7.2%
Trans-porters	50	6	$160,300	42-40	26-39	$149,722-$139,133	$10,578-$21,167	6.6%-13.2%

The jet group has the greater saving potential by introducing a cost-effective training mix. the helicopter group training mix can be considered as cost effective, and only by introducing a 90% learning curve in the simulator training hour cost estimation model, a saving of up to 7.2% can be achieved.

A potential saving of $10,578 - $21,167 of the existing cost of training a pilot can a achieved in the transports group.

In the context of these results, the following remarks have to be considered:

(a) Multiply the cost saving by the numbers of pilots; this will not change the order of potential cost saving. On the contrary, the jet group will stay high in the list.

(b) Two conservative constraints have been used in the model:

(1) Simulator hours cannot exceed flying hours.

(2) Total training hours cannot exceed 50% of the existing total training hours.

(c) The cost of an average simulator hour is a very powerful factor in the model. This can be demonstrated by the following examples:

(1) In the Jet group, the existing constant cost of a simulator hour is $566, which is 6.6% of the flying hour cost. Using the constant average cost model, 67 simulator hours, which is 11 times the existing simulator hours, have to be introduced in the cost effective model.

(2) In the Transport group, the existing constant cost of a simulator hour is $550, which is 17.5% of the flying hour cost. Using the constant average cost model, 32 simulator hours, which is only 5.3 times the existing simulator hours, have to be introduced in the cost effective model.

(3) In the Helicopter groups, the constant cost of a simulator hour is $562, which is 25% of the flying hour cost. Using the constant average cost model, the existing 20 yearly simulator hours are cost effective.

Although the relative cost of the simulator hour is not the only factor that influences the model results, it is obvious from the above examples that reducing the simulator hour cost has a great saving potential.

Finally, the results of the example analysis show a very large increase in simulator hours. Such an increase has various implications that were not examined in this paper, but should be examined when updating the model constraints.

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